



CMS Pixels in Test Beam

The CMS pixel Test Beam group

Lorenzo Uplegger

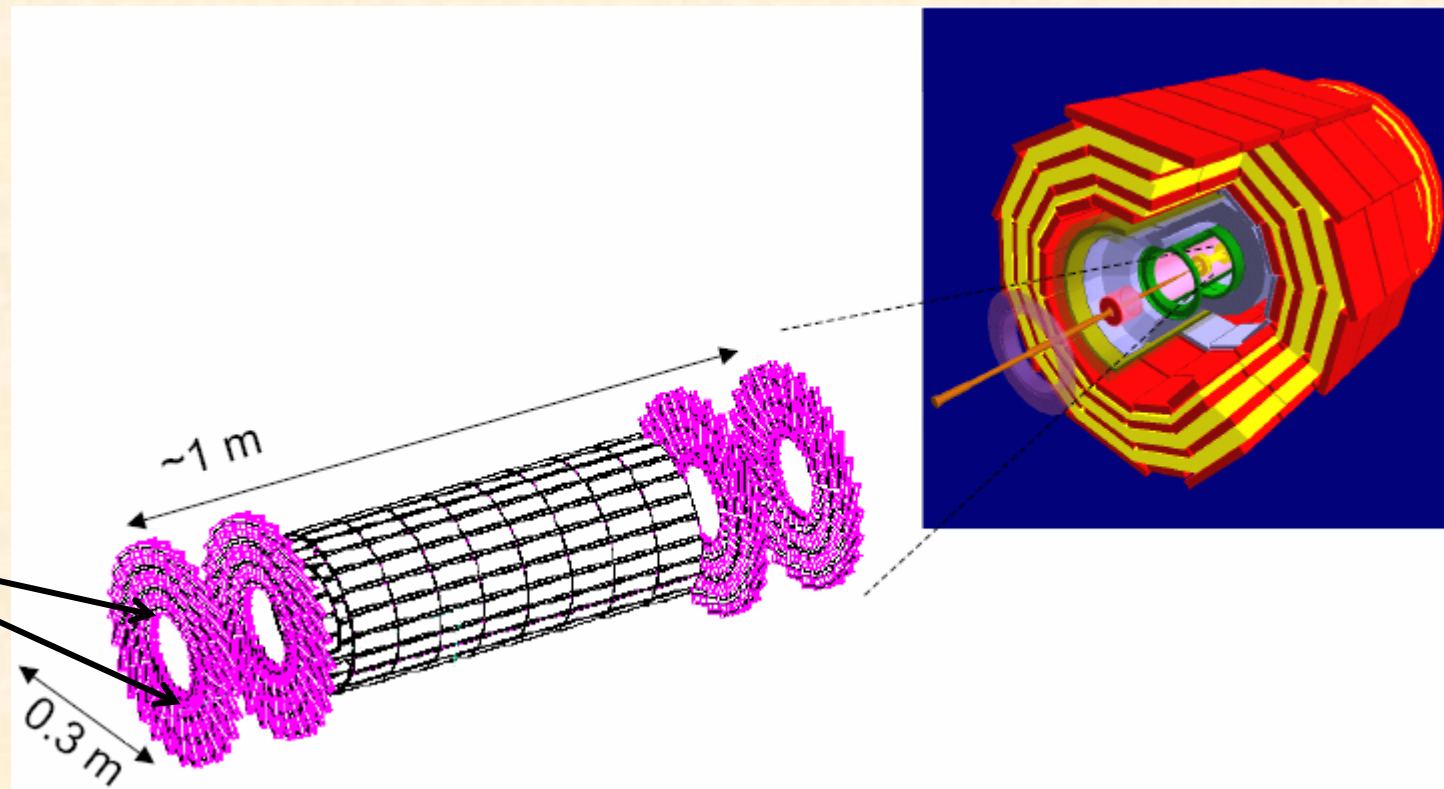
CMS pixel detector



The CMS pixel detector will work in a very high radiation environment. The central region close to the beam will receive 10 Mrad of radiation every year, at a luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$.

It is crucial to understand the effects of this high radiation environment on the efficiency and behavior of the detector in order to understand the impact on the physics of the LHC.

10Mrad x year
(@ $10^{34}\text{cm}^{-2}\text{s}^{-1}$)



Test beam runs



In September 2005 we irradiated four detectors and then in February we could test them in the beam here at the MTEST facility.

Most of the results discussed in this talk were obtained with a detector irradiated up to $3 \cdot 10^{13} \text{ p(200 MeV)/cm}^2$ ($\sim 2\text{Mrad}$).

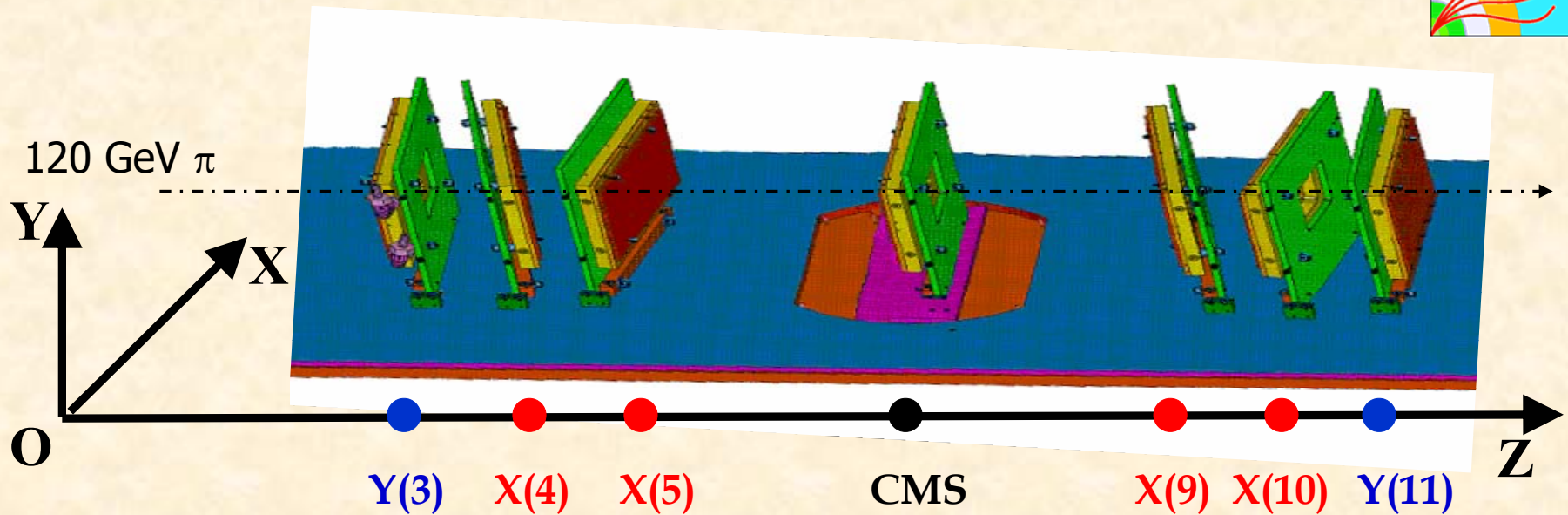
The goals of this test beam were to study the charge collection efficiency and the eventual loss in efficiency and resolution.

The results are encouraging since we observe an efficiency of 100% everywhere, with just a small charge loss in the corners of the pixels where there is charge sharing.

Once we were confident that the detectors could absorb few Mrad, in May 2006 we irradiated another one at a much higher dose, $8 \cdot 10^{14} \text{ p(200 MeV)/cm}^2$ ($\sim 45\text{Mrad} = 4.5 \text{ years in LHC}$), which exceed the radiation dose at which the detector is required to remain operational ($6 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$)

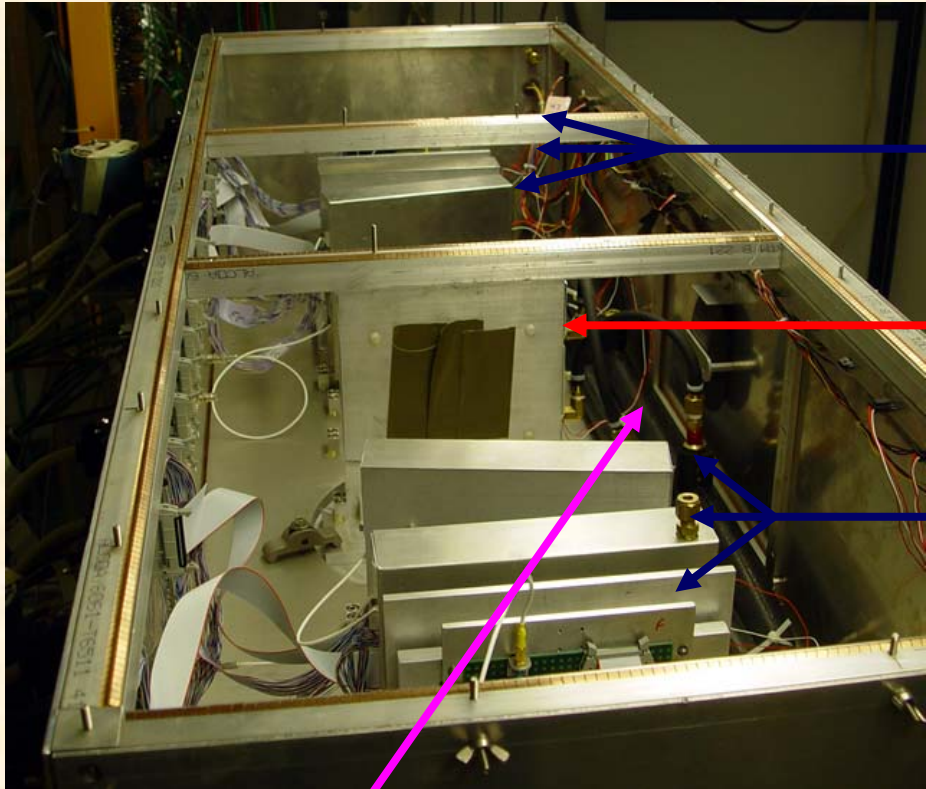
The study of the most irradiated one are under way, but given the preliminary efficiency, also at this high irradiation dose the detector is working well.

Experimental setup



- Telescope of 6 BTeV pixel detectors ($50\text{ }\mu\text{m} \times 400\text{ }\mu\text{m}$)
 - 2 Y-measurement planes \Rightarrow Y-resolution $\sim 6.24\text{ }\mu\text{m}$
 - 4 X-measurement planes \Rightarrow X-resolution $\sim 4.75\text{ }\mu\text{m}$
- CMS pixel detector in the center ($100\text{ }\mu\text{m} \times 150\text{ }\mu\text{m}$)
- Triggers to CMS detector are provided by two upstream scintillators

Experimental setup



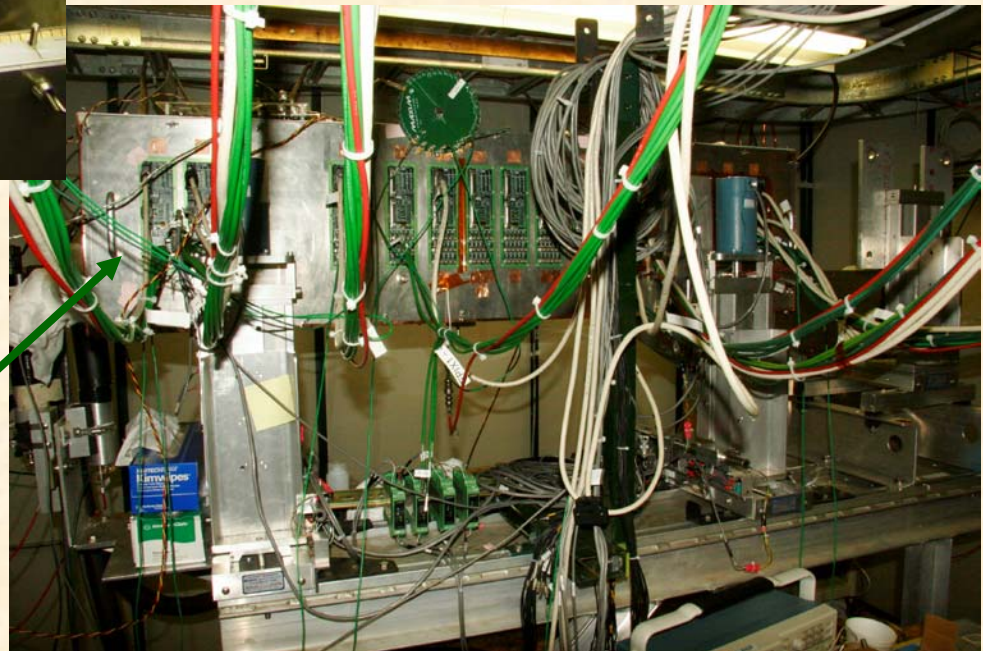
Upstream Telescope Planes

CMS detector under test

Downstream telescope planes

Cooling system

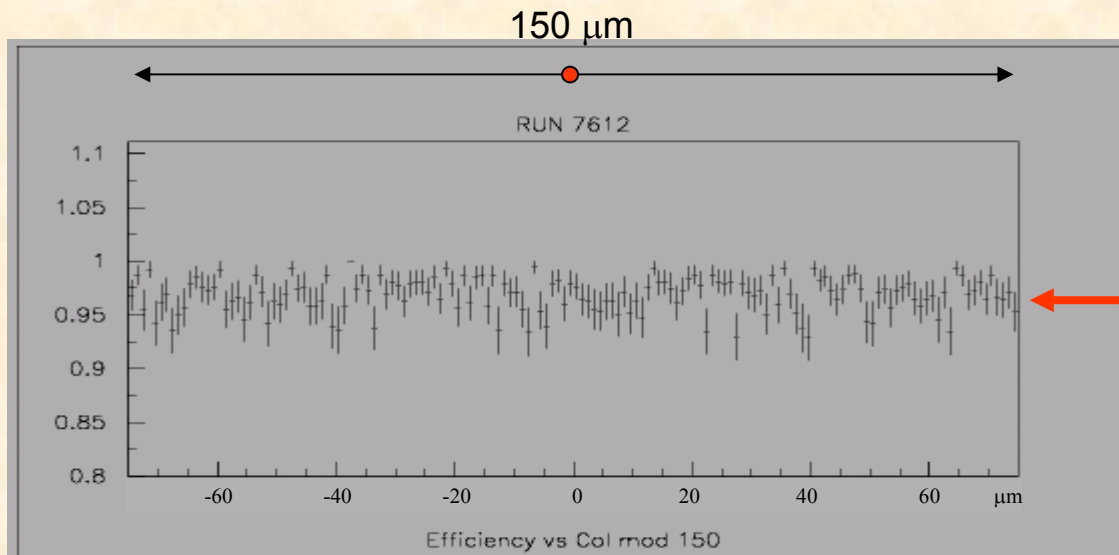
Side view of the system



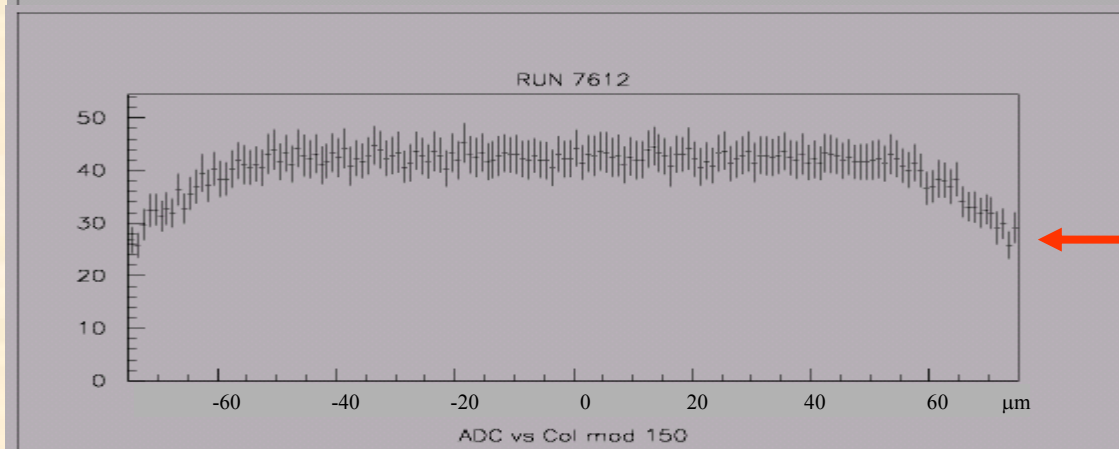
Efficiency studies across pixel cells



- We do not find any sign of efficiency loss in any particular spot of the pixel cells.
- The apparent missing efficiency is due to the completely different readout philosophies of the telescope (data driven) and the CMS pixel (triggered). This apparent inefficiency has been well understood and is generated by a sequence of two particles arriving close in time.



Efficiency across a pixel cell



Charge collection efficiency across a pixel cell

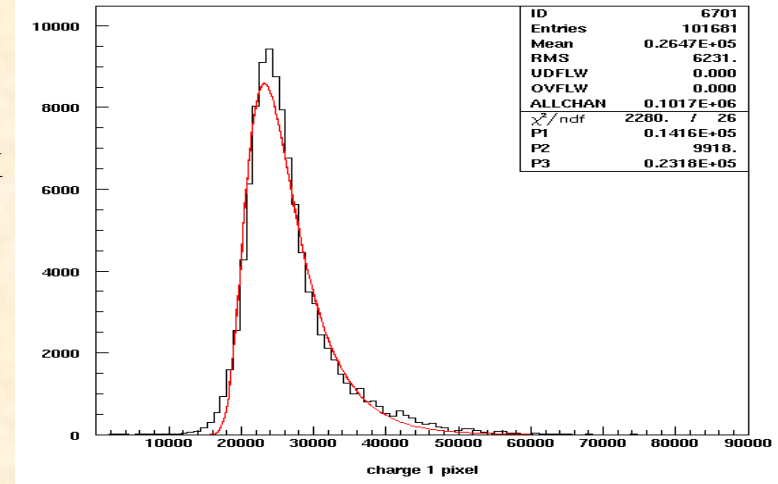


MIP charge curve shape

After the electronic calibration of all pixels we can convert our ADC units in electrons with the conversion factor of 1 ADC = 60 electrons

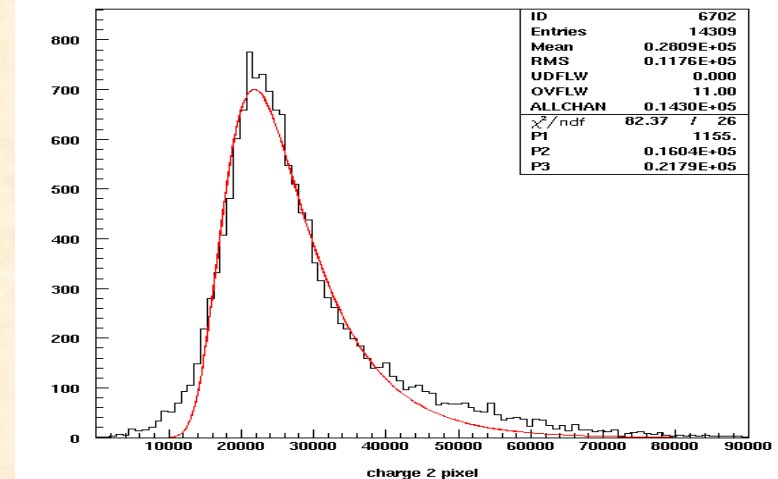
Events with only 1 pixel firing (no charge sharing)

- Landau curve peaked at ~23k electrons, $\Gamma \sim 10k$



Events with 2 pixels firing (charge sharing)

- Total charge = sum of the charge of 2 pixels
- Landau curve peak at ~22k, $\Gamma \sim 16k$ electrons
- Peak consistent with that of one pixel.
- Γ is obviously wider





Resolution

1 pixel events

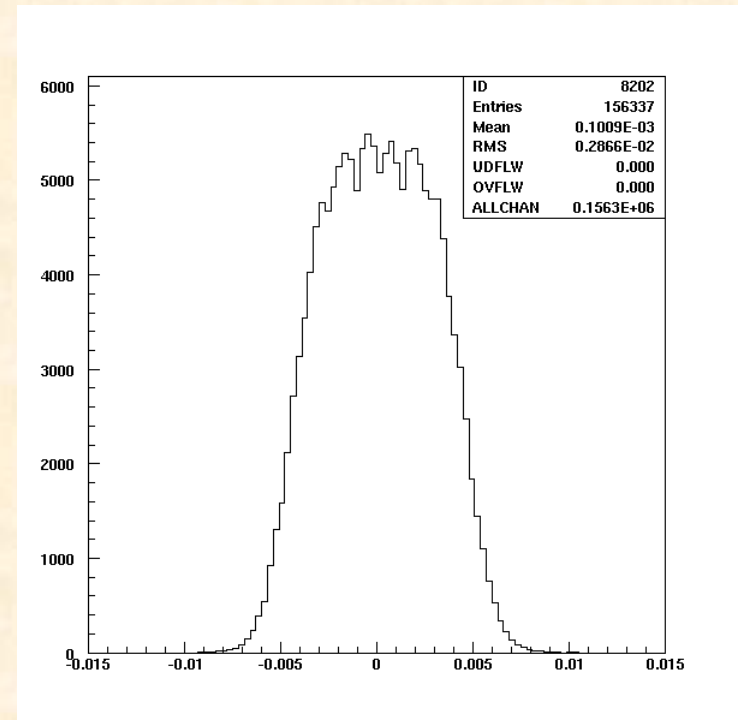
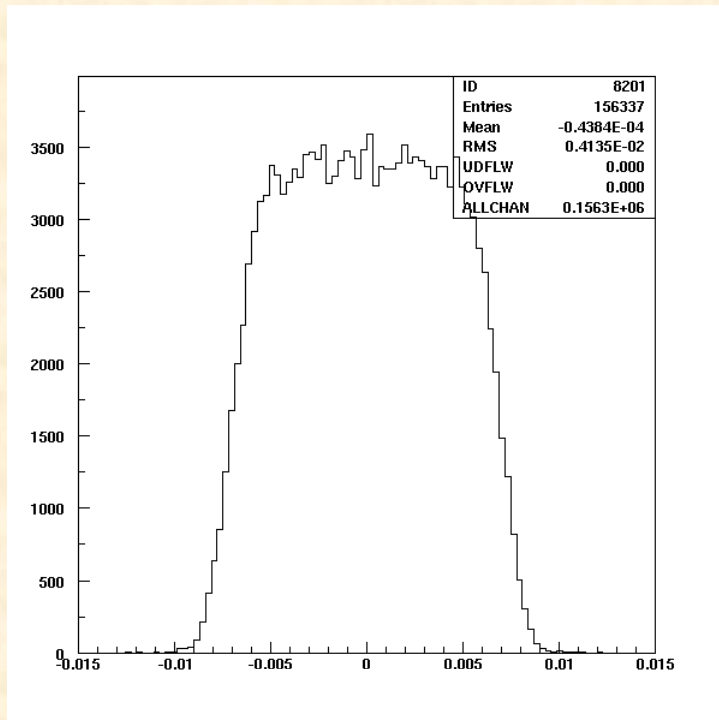
CMS hit excluded from the fit

- Pitch size 150 μm
- $\text{RMS}(x) \sim 41.4 \mu\text{m}$

$$\begin{aligned}\text{res}_{\text{det}}(x) &= \sqrt{\text{RMS}^2 - \text{res}_{\text{tel}}^2} \\ &= \sqrt{41.4^2 - 4.8^2} = 41.1\end{aligned}$$

- Pitch size 100 μm
- $\text{RMS}(y) \sim 28.7 \mu\text{m}$

$$\begin{aligned}\text{res}_{\text{det}}(y) &= \sqrt{\text{RMS}^2 - \text{res}_{\text{tel}}^2} \\ &= \sqrt{28.7^2 - 6.2^2} = 28.0\end{aligned}$$



Both consistent with: $\text{pitch}/\sqrt{12}$

Resolution for charge sharing

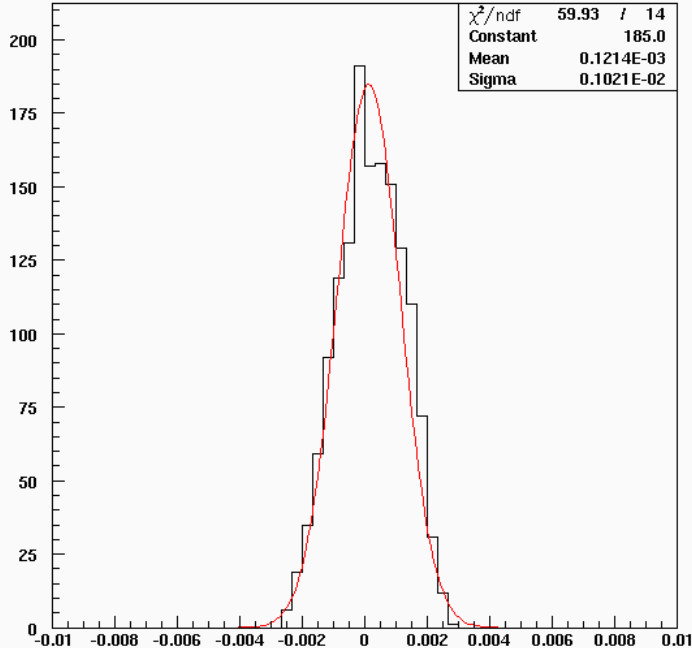
2 pixels events

CMS hit excluded from the fit



2 columns - 1 row events:

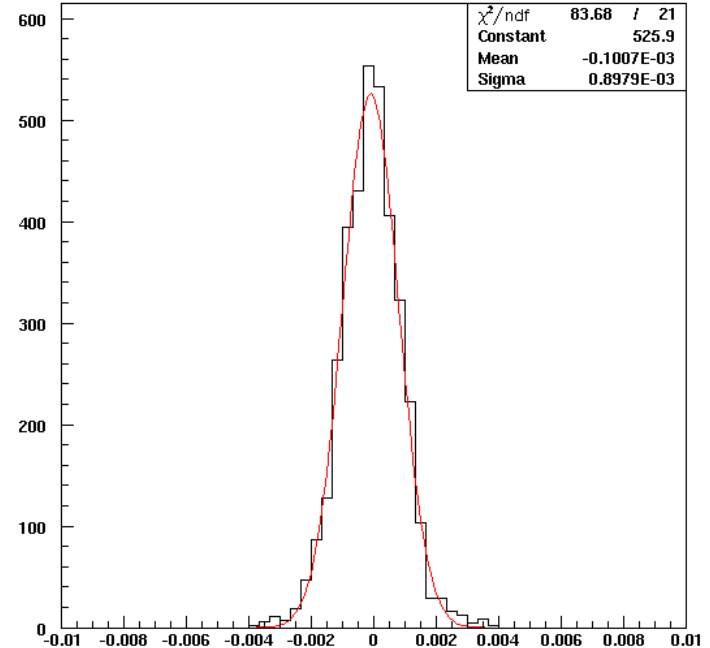
Charge sharing in x direction



$\sigma_x = 10.2 \mu\text{m}$ \Rightarrow $\text{res}(x) = 9.0 \mu\text{m}$

1 column - 2 row events:

Charge sharing in y direction



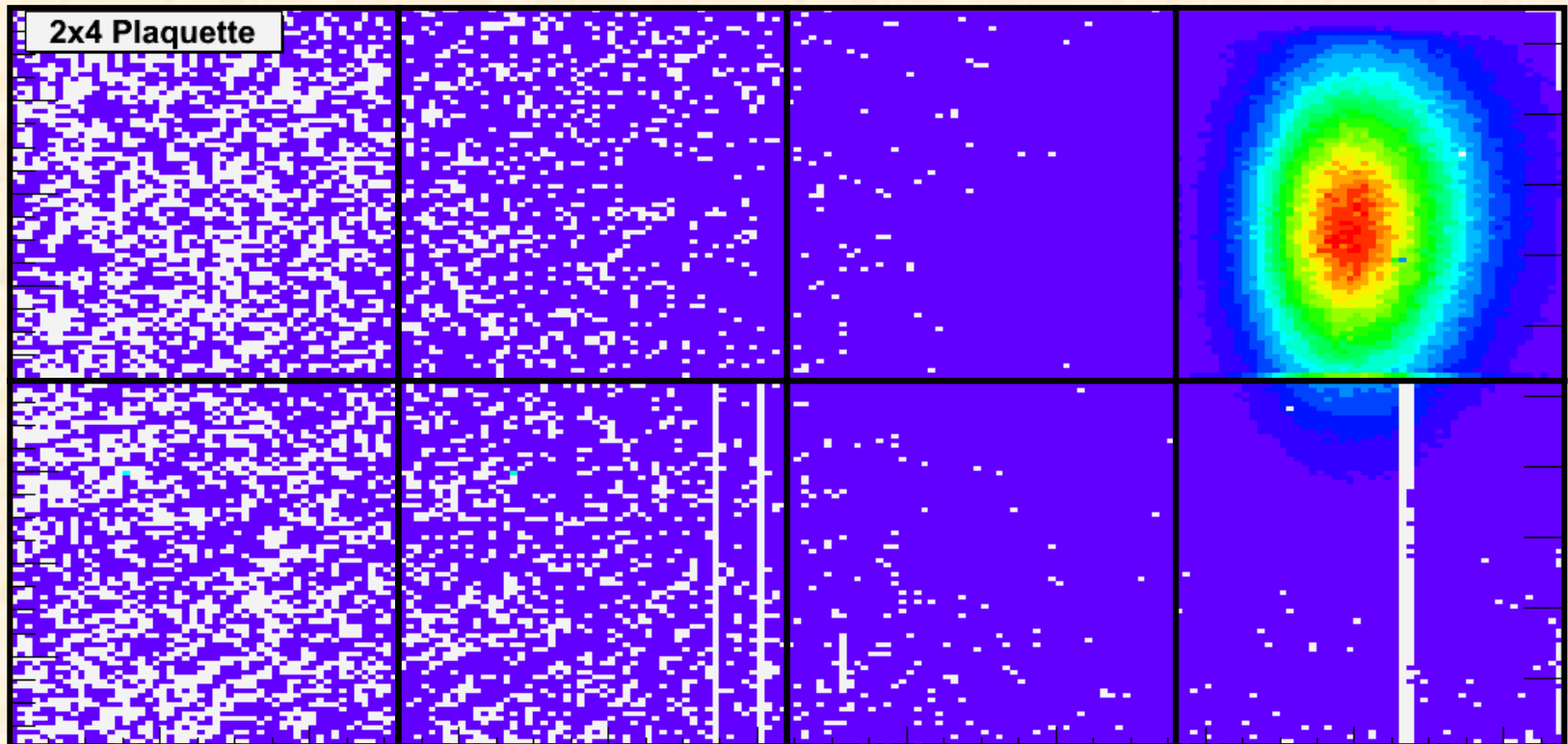
$\sigma_y = 9.0 \mu\text{m}$ \Rightarrow $\text{res}(y) = 6.7 \mu\text{m}$

Highly irradiated detector

In July we started a second campaign to study the effects of radiation on a 8 chips module irradiated in May 2006 up to a dose of $8 \cdot 10^{14}$ p(200 MeV)/cm² (~ 45 Mrad = 4.5 years in LHC).

The detector was irradiated in one corner with the idea to study the efficiency across the module since the read-out chips absorbed different doses.

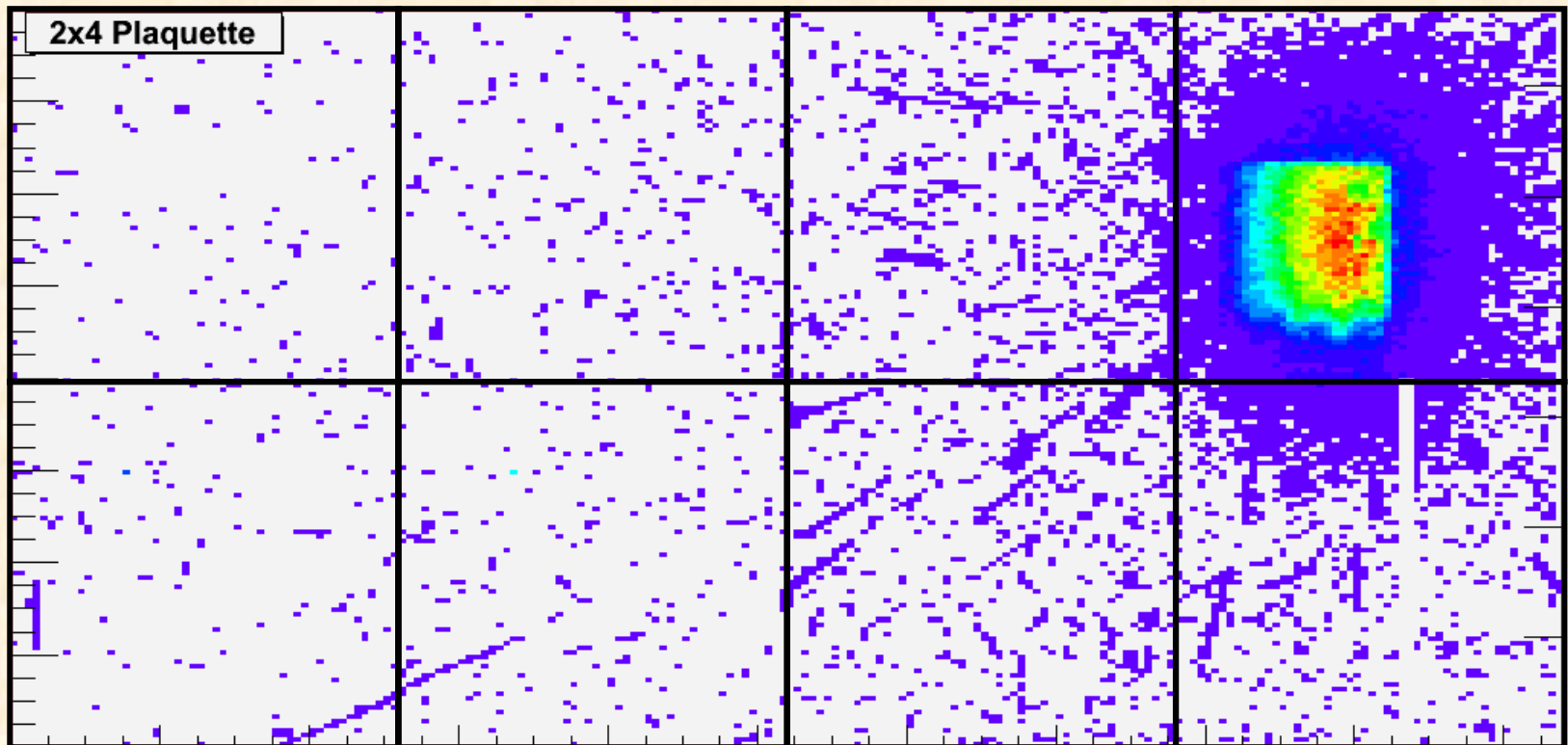
All triggers from scintillator



High irradiated detector



Coincidence with the telescope: highlight of detectors overlap

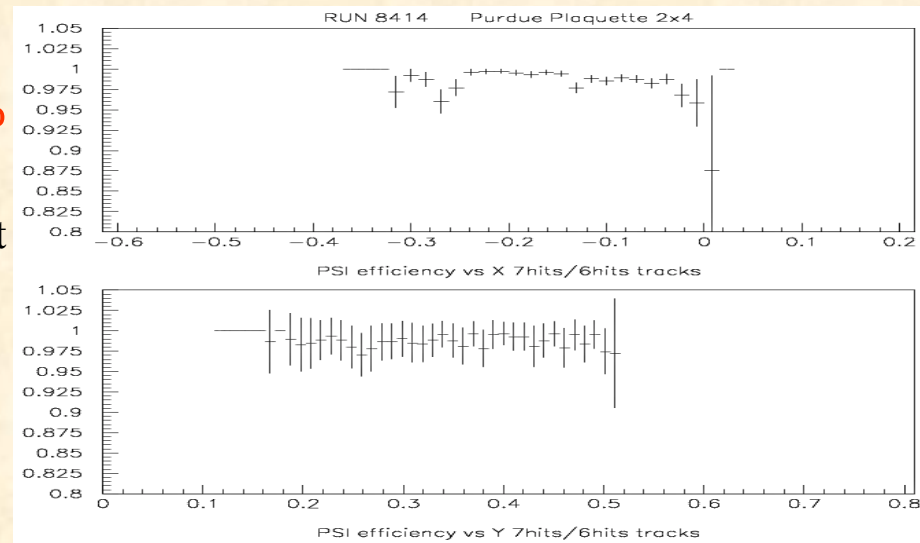


Preliminary results



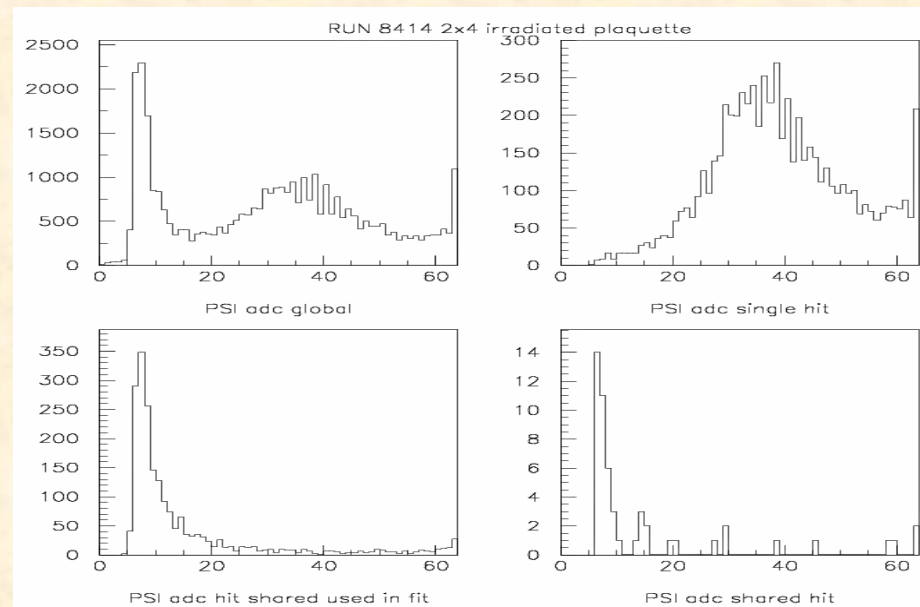
Good reconstruction efficiency $98.8 \pm 0.1 \%$

- very likely this is due to the fact that now they extract a single batch per revolution in contrast with what they did in January (2 per revolution), thus reducing the probability for a second particle to fall within our timestamp window



Higher bias voltages are required to collect the whole charge

- even in the less-irradiated areas, detector performance improves by raising bias from 300 V to 500 V



Conclusions



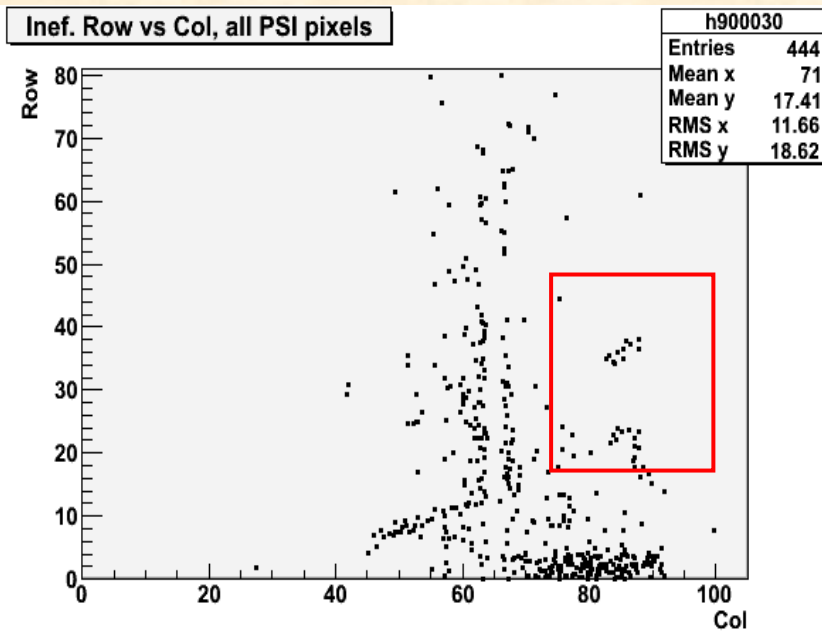
- The results of the irradiated ($3 \cdot 10^{13}$ p(200 MeV)/cm²) detector under test in the January test beam show no significant effects due to radiation damage.
- The efficiency is 100% also in regions of the pixel cells where there is charge sharing
- A small charge loss is measured on the borders of the pixel cells where the charge is split between two pixels
- The resolutions of 1 pixel (no charge sharing) are consistent with the expected resolution of $\text{pitch}/\sqrt{12}$.
- The resolutions of 2 pixels tracks, which will be the vast majority of events in the final detector configuration given the optimized geometry to maximize charge sharing, are:
 - $\text{res}(x)=9.0 \mu\text{m}$ (two columns)
 - $\text{res}(y)=6.7 \mu\text{m}$ (two rows)
- We must thank all the people who allowed us to take data again during last week, since we were able to test the most irradiated detector in the spot where we concentrated the highest radiation dose
- Thanks to this last few days of beam we were able to finish our summer Test Beam program
- The preliminary results for this very highly irradiated detector show almost no degradation of performances but, as expected, it is necessary to increase the bias voltage in order to collect as much charge as possible.



Where is this loss coming from ?



- The BTeV telescope doesn't use any trigger signal, because the ROCs are data driven, so hits are time-stamped on the chip and sent to the read-out system.
- All the BTeV ROCs are synchronized with a 2 MHz clock (500ns) in order to get the same timestamp from the hits generated when a particle passes.
- The CMS chip is triggered by two scintillators and hits are time stamped in the read-out electronic with the same 2 MHz clock used for the telescope.
- To build events we group together hits with the same timestamp but we allow a window of 3 clocks ($1.5 \mu\text{s}$).
- To protect the readout of the CMS events we also veto triggers that are closer than $4 \mu\text{s}$, only in the CMS ROC since the telescope is data driven.



The inefficient events are characterized by another track at least passing outside the region covered by the telescope and hence impossible to be reconstructed

- This first track is the one firing the CMS trigger
- The track that is reconstructed by the telescope is coming in later...but it doesn't leave a hit in the read-out of the CMS ROC since we veto a new trigger for $4 \mu\text{s}$ after the first track.

In Conclusion:

The measured CMS pixel inefficiency is just an apparent effect generated by a sequence of two particles at least, which fall in the same time-stamp cycle ($500 \text{ ns} \times 3 \text{ clock cycles}$), but not in the same CMS readout gate ($\sim 3815 \text{ ns}$)

Resolution studies

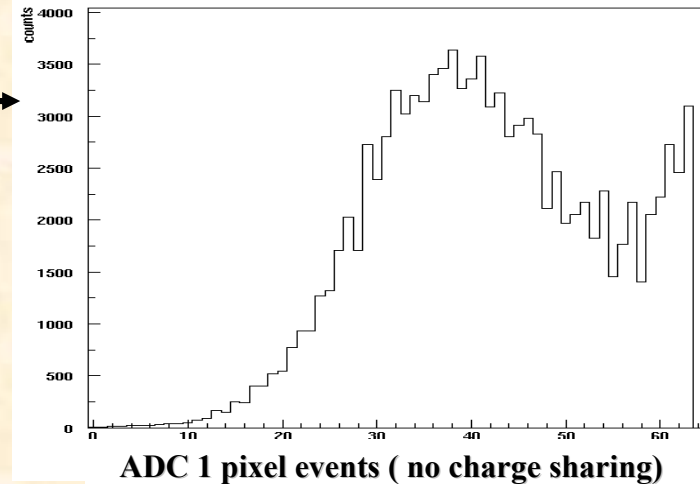


1 pixel clusters charge

ADC charge measured on CMS for tracks which left only 1 pixel hit

ADC plot shape (uncorrected data):

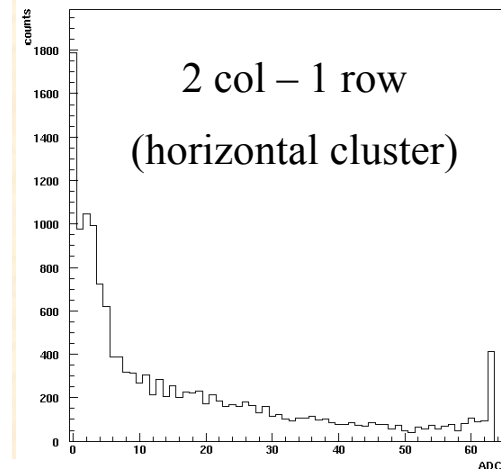
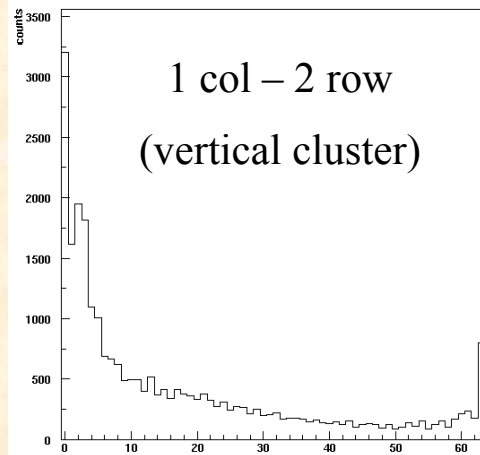
- Peak at ~38 adc units
- Spread of saturation peak at high adc values



2 pixels clusters charge

ADC charge measured on CMS for tracks which left charge on two adjacent pixels

ADC plot shape (uncorrected data)



ADC 2 pixels events (charge shared between two pixels)

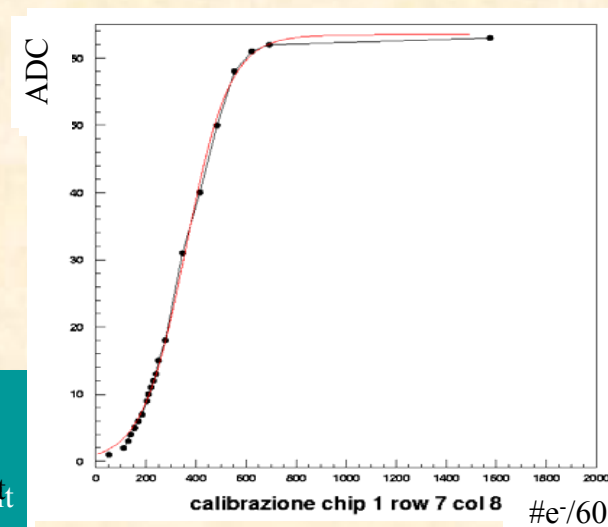
Electronic calibration



Injecting charge with the internal calibration circuit we calibrate all the pixels in the ROC, but as we can see here the conversion between $V_{cal} \Rightarrow ADC$ is nonlinear. The function that we need to use to fit is a Fermi like function:

$$y = par(1) \cdot \frac{1}{1 + e^{\frac{par(2)-x}{par(3)}}}$$

par(1) saturation value
par(2) charge value at half of par(1)
par(3) slope of the central part of the fit



Inverting the function we can convert ADC into charge using parameters from the fit in the inverted function

$$x = par(2) - par(3) \times \ln \left(\frac{par(1)}{ADC} - 1 \right)$$

Not a very good fit at very low adc value

We reject $ADC \geq par(1)$

